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Size and orientation of burrows made by the earthworms *Aporrectodea rosea* and *A. caliginosa*

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ABSTRACT

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The morphology of surface-opening burrows made by earthworms in a South Australian duplex Red-brown Earth was investigated. Coordinate points along burrows were measured during careful excavation. Burrow length, orientation and the frequency of branching were measured. Mean burrow length was 398 mm (s.d. = 189) with typically 2 to 3 branching points. Polar coordinate representation of the burrows showed them to be nearer to vertical at greater depths. Maximum depth of excavated burrows was approximately 250 mm, placing them almost entirely in the soil A horizon.

INTRODUCTION

Earthworms move through soil, creating burrows. Lee (1985) has described three principal forms of burrows. These are usually vertical burrows, sometimes with branching near the surface as described by Lamparski et al. (1987); burrows of geophagous species that forage for food in the subsurface soil horizons but which are predominantly horizontal with some surface openings; and the more or less vertical burrows made by surface-living earthworms as a retreat during dry or cold seasons. The intensity of burrowing activity by geophagous species is related to food supply (Martin, 1982) as well as temperature and water availability.

Burrows, as with biopores in general are cylindrical channels and have been described as important for water and air movement through soil (Ehlers, 1975) and possibly provide paths for plant root growth (Dexter, 1986; Jakob-

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sen and Dexter, 1988). The significance of the size, orientation and longevity of single burrows formed by geophagous species has not been extensively examined although Kretzschmar (1982, 1988) has studied seasonal variations and used simulations to describe burrow systems. Kretzschmar (1978, 1982) found that different ecological groups of earthworms contribute to the different burrow forms and that the quantity of burrows varied through the year and was well correlated with the soil water content and temperature. He found most burrows between 20 and 40 cm deep in the soil. To describe their orientation he used the terms sub-horizontal and sub-vertical.

Data on the numbers of burrows per unit area and the diameters of these burrows have been presented by Barley (1959), Ehlers (1975) and Omoti and Wild (1979). Rogaar and Boswinkel (1978) examined burrows in a polder with a mixed earthworm population and noted two types of burrows; predominantly vertical burrows up to 8 mm wide continuing to depths approaching 1 m, and twisting burrows of 0–8.5 mm diameter down to a maximum of 270 mm. Vertical burrows were attributed to *Lumbricus terrestris*, while the less deep burrows were attributed to several species, including *Aporrectodea caliginosa* and *A. rosea.*

The objective of this study was to examine the suitability of using coordinate points derived from excavation of burrows as a method of quantifying burrow architecture and to use geometrical representation of the data obtained to quantify changes in length and direction of burrows.

MATERIALS AND METHODS

Site and soil

The site chosen for investigation was in a permanent pasture of *Trifolium subterraneum* L. and grasses growing in the Urrbrae fine sandy loam of the Red-brown Earth group (Oades et al., 1981) at the Waite Agricultural Research Institute (34°58'S, 138°38'E).

The A1 horizon has 17% clay ($<2\ \mu m$), contains no calcium carbonate and extends to a depth of approximately 150 mm. It lies over an A2 horizon extending a further 150 mm (Oades et al., 1981) below which is a clay (65% $<2\ \mu m$) B horizon. There had been no tillage at the site for many years but super-phosphate fertilizer had been broadcast 4 months before the commencement of this study. The area has a Mediterranean type climate with a warm, dry summer and a cool, wet winter. Most of the mean annual rainfall of 586 mm falls between May and October. The area was not irrigated. Soil temperatures at 150 mm depth range from a mean daily maximum of 30.3°C in January to a mean daily minimum of 9.7°C in July (Waite Agricultural Research Institute, 1987). The excavation of burrows reported here was done between August and mid-October, 1986.

Method for mapping surface-open burrows

An aluminium framework 1.2 m$\times$1 m (Fig. 1) was placed flat on the soil surface. In tracks along the sides 1 m apart a trolley could be moved (in the x-direction). A wheel-mounted pointer on the trolley could be moved (in the y-direction) at right angles to the direction of trolley movement. The pointer which could be lowered and raised (in the z-direction) could be fixed in place with a screw. Metal tapes marked at 1 mm intervals were fixed to the framework. Moving the trolley and the pointer on the horizontal plane enable the x and y coordinates to be determined, with the vertically moving pointer allowing the z coordinates to be read from a scale. The entire framework weighed approximately 25 kg and could be dismantled for easy transport.

When in use, the framework was first positioned, and then the soil surface was examined for any biopores opening to the surface. The presence of cast material on the soil surface was used to locate likely starting points. Only burrows open to the surface were mapped. Once a surface opening of a burrow had been found, the above ground parts of the vegetation in the immediate vicinity were removed using scissors. Care was taken not to disturb the soil.

After the coordinates of the surface opening had been recorded, mapping of the burrow proceeded by gently inserting a dissection probe a short dis-

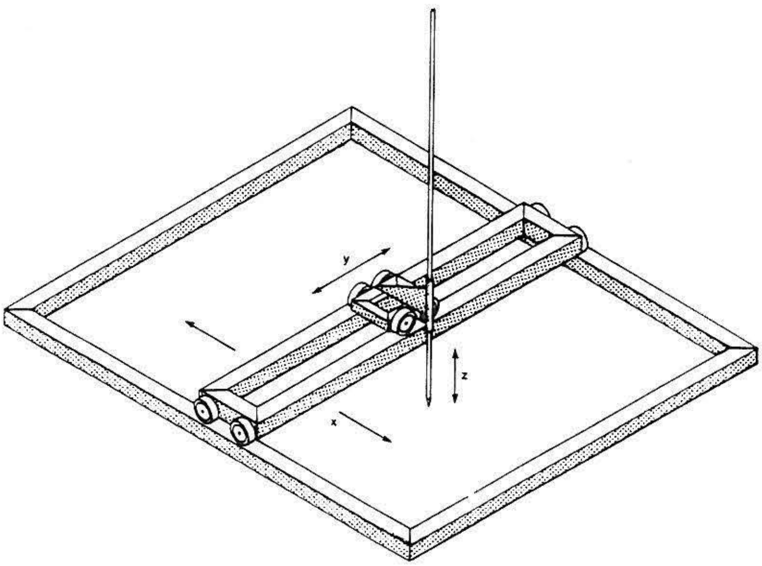

Fig. 1. Aluminium framework used for mapping earthworm burrows showing the trolley for movement in the x-direction, and the wheel mounted pointer for movement in the y- and z-directions. Dimensions are 1.2 m by 1.0 m. Pointer length 1.0 m.

tance into the biopore, or until resistance was detected. The soil was then excavated around the probe using spatulas and fine brushes. The coordinates of the newly exposed point were recorded and the procedure repeated. Coordinate readings were taken in approximately 15 mm segments. Earthworms found in the burrow were collected, anaesthetized and returned to the laboratory for identification. The coordinate data were then transferred to computer disc. As there was some skewing of the trolley as it was moved, the x coordinates were measured at each end of the trolley and the mean value calculated to overcome the parallax. From the x, y, z coordinates the length and orientation of each segment of the burrow were calculated.

Techniques for geometrical description of linear and planar features in soil have been reported by Willoughby (1967). The technique is readily applicable to the description of burrows created by earthworms particularly if (x, y, z) coordinate measures are available of burrows.

RESULTS AND DISCUSSION

Sixteen burrows (open to the surface and containing at least one adult earthworm) were mapped in their entirety. For these burrows the mapping process was not stopped by an inability to follow the burrow (e.g. around plant roots) or because the excavation process destroyed unmapped parts of the burrow. Rovira et al. (1987) observed during sampling of *A. caliginosa* populations that many small worms were associated with plant roots. Similar associations were a major cause of difficulties in mapping burrows here. For each successful burrow excavation there were more than five incomplete excavations. Only one burrow contained more than one adult worm.

The mean length of the burrows was 392 mm (s.d. = 189). All the burrows were produced by either *A. rosea* or *A. caliginosa*, ten by the former and six by the latter. The only other species found at the site was *Microscolex dubius*. As suggested by Lee and Foster (1991) it was not possible to correlate any macroscopic measurements of soil physical properties such as water content with individual earthworms. Similarly no correlation between the fresh weight of the earthworms and burrow length or depth was found.

The number of surface openings per burrow is shown in Fig. 2. The mean number of surface openings per burrow is 3.2 (s.d. = 1.8). The mean number of branches (i.e. points from which more than two paths lead) per burrow was 2.7 (s.d. = 2.0). The majority of branches were in the top 50 mm of soil (Fig. 3). The numbers of surface openings and branches were both positively correlated (at the 5% level) with burrow length. The distribution of burrow length with depth is shown in Fig. 4 with the greatest depth of 195 mm.

The angle and length of burrows occurring in 50 mm layers from the soil surface is shown in Figs. 5, 6 and 7. These were plotted using the technique of Willoughby (1967). The burrow sections are divided into 5° increments and

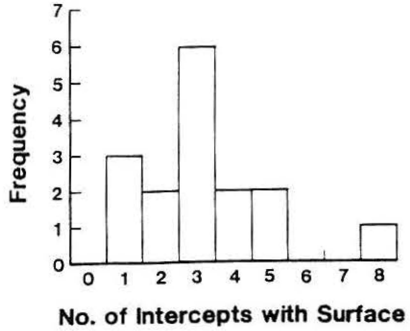

Fig. 2. Histogram of the number of surface openings per burrow.

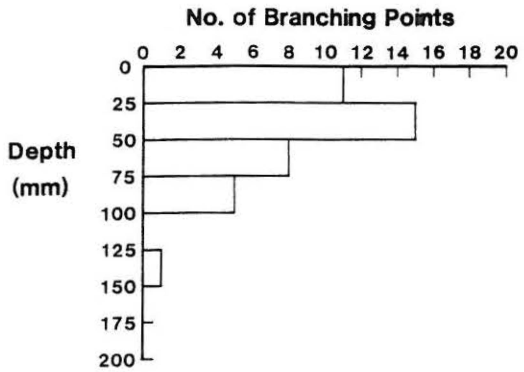

Fig. 3. Number of burrow branching points as a function of depth, in 25 mm increments.

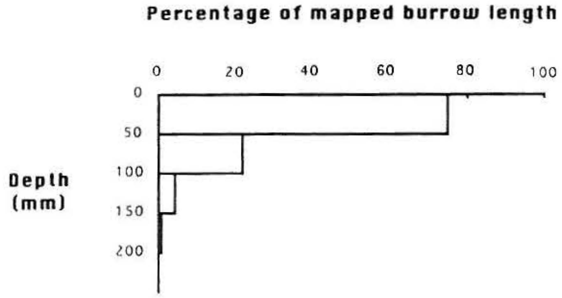

Fig. 4. Percentage of burrow length as a function of depth, in 50 mm increments.

the total length of burrow in each increment plotted. As only 53 mm of burrow was mapped below 150 mm depth these are not graphed, but the mean angle of these burrows was 61.3° measured from the horizontal. Figure 8 shows the relationship between the mean angle, θ, that the burrow makes with the horizontal and the mean depth, z (mm), of that layer. Regression yields:

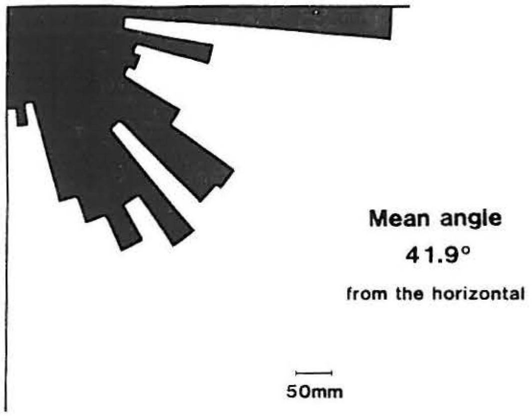

Fig. 5. Polar coordinate representation of burrow length and angle in 5° increments, for 0–50 mm soil depth.

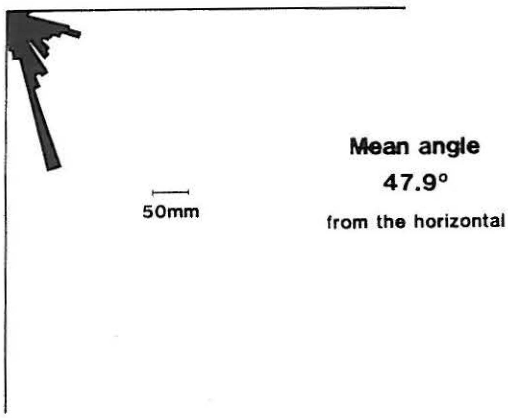

Fig. 6. Polar coordinate representation of burrow length and angle in 5° increments, for 50–100 mm soil depth.

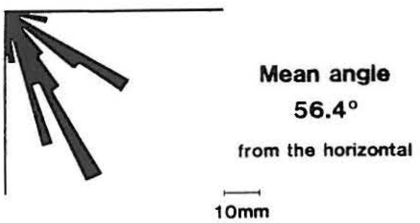

Fig. 7. Polar coordinate representation of burrow length and angle in 5° increments, for 100–150 mm soil depth.

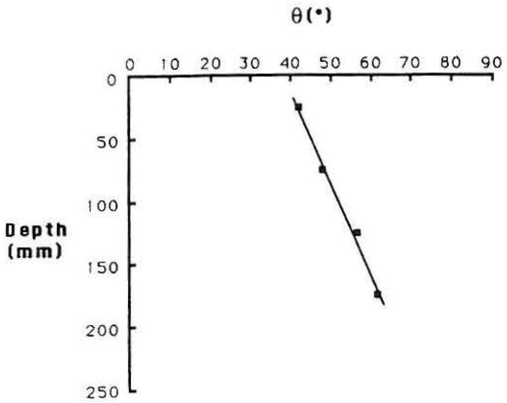

Fig. 8. Changes in the mean angle, $\theta°$, made between the burrow and the horizontal with depth, in mm.

$$\theta = 35.20 + 0.13z \quad R^2 = 0.99 \tag{1}$$

The boundary conditions are $z > 0$ mm (since burrows cannot occur above the soil surface) and $z < 410$ mm (since burrows cannot exceed 90° from the horizontal). At this site Barley (1959) noted that burrows in the top 150 mm were irregular but that at greater depths they seldom branched and that they had the form of nearly vertical cylinders.

Plant roots growing vertically in this soil are more likely to encounter burrows near the soil surface as this is where burrows are nearest to horizontal. Dexter (1986) and Jakobsen and Dexter (1988) have illustrated the importance of vertical biopores for root growth, particularly for penetration of compacted soil. Dexter and Hewitt (1978) have shown that plant roots meeting an interface within the soil are frequently deflected. Plant roots which encounter earthworm burrows are likely to be deflected and follow a path of least resistance which will usually be downwards along the burrow.

If the additional measurement of burrow diameter was taken for each excavated segment, burrow volume could be estimated. Knowledge of the existing burrow volume at given depths together with earthworm numbers and ingestion rates may allow the longevity of burrows at various depths to be calculated by comparing the volume of burrow produced with that mapped.

CONCLUSIONS

The geometry of surface open pores is an important factor in water and air movement in soils. The techniques described in this paper show that it is possible to quantify and clearly present information on earthworm burrows using the geometrical presentations of Willoughby (1967). The technique is also

likely to be suitable for quantitatively describing burrows of other soil fauna. No correlations were found between any of the burrow parameters measured here and soil water content or soil temperature. Because the burrows found at this site had a mean length of only 392 mm and a depth not exceeding 250 mm the size of the framework used for mapping could be reduced for future measurements. Preliminary excavations at other sites would indicate appropriate dimensions for other species. Burrows created by *A. rosea* and *A. caliginosa* were not vertical near the soil surface but tended toward vertical with increasing depth. We have quantified the observation of Barley (1959) that burrows at this site seldom branched below 100 mm depth.

ACKNOWLEDGMENT

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